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TRANSFORMATION TOWARDS SUSTAINABLE
AND RESILIENT WASH SERVICES

Modelling nitrogen and phosphorus dynamics in soil fertigated with decentralised wastewater treatment effluent

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Many residents in informal settlements lack proper sanitation. The decentralised wastewater treatment system (DEWATS) is a low-cost water borne onsite technology that can potentially provide sanitation in unserved areas. The management of DEWATS effluent is of environmental concern. Its use in agriculture helps improve livelihood and food security in peri urban areas. This study investigated environmental sustainability for fertigation using DEWATS effluent through modelling N and P dynamics in fertigated soils. The SWB Sci model, a crop growth and nutrient (N and P) simulation model was calibrated and validated based on field experiments conducted. The crop growth sub-model was successful and met all statistical criteria ($r^2 > 0.8$ and $D > 0.8$). Use of DEWATS effluent showed to increase soil inorganic N and P within the top soil layers (0.3 m), which may be beneficial for crop production. However, proper management practices are recommended to prevent leaching and runoff losses.

Introduction

The provision of sanitation in unserved informal settlements of the cities periphery is a problem due to uncontrolled urbanisation (Ashipala & Armitage 2011). Therefore, onsite sanitation has been considered as a solution in such areas. Ecological sanitation technologies such as ventilated improved pit (VIP) latrines, urine diverted dehydrated toilets (UDDT) and decentralised wastewater treatment systems (DEWATS) have considered as potential solution to onsite sanitation (Tilley 2014). The DEWATS is a modular water borne low cost onsite sanitation technology that degrades organics such as human excreta waste to produce effluent rich in N and P (Gutterer *et al.* 2009). Discharging of treated wastewater into water bodies causes pollution, therefore it must conform to stringent international standards (USEPA 2012).

Climate change have contributed to low and erratic rainfall, contributing to food insecurities in low income countries. Reuse of water in agriculture has been considered as one of the mitigation strategies (WWAP 2017). Use of wastewater in agriculture has been reported to improve soil chemical properties and nutrient uptake by crops thereby increasing crop yields (Jaramillo & Restrepo 2017). However, there are some drawbacks such as effects on human health, crops and the environment. There are several guidelines to mitigate effects on health (WHO 2016), crops (FAO 1985) and the environment (USEPA 2012).

Wastewater provide inorganic N and P in the soils which undergo different dynamics (Jaramillo & Restrepo 2017). Nitrogen is nitrified to produce NO_3^- which can be retained, taken up by crops or lost through denitrification (N_2O and N2) and leaching (Levy *et al.* 2011). Phosphorus is retained through precipitation or adsorption processes in the soil and can be available for crop uptake through dissolution and desorption processes (Levy *et al.* 2011). The effects on the environment through leaching and runoff losses is affected by soil type, irrigation management practices and rainfall (Brady & Weil 2016). Understanding N and P dynamics in soils fertigated with wastewater allows implementation of management practices to prevent environmental pollution.

Comprehensive information on N and P dynamics in soil can be generated from several studies in different locations with variable climatic conditions. This is expensive and time consuming hence mechanistic models can be used (Tesfamariam *et al.* 2015). The SWB Sci is a robust mechanistic irrigation scheduling and nutrient simulation model which can be used in environmental studies (Tesfamariam *et al.*

2015). This study therefore aimed at assessing the suitability of an SWB Sci in modelling banana growth and nutrient (N and P) modelling in DEWATS effluent fertigated soils and use the information to develop management strategies. The specific objectives were to (i) calibrate and validate the SWB Sci in simulating crop and N and P dynamics in DEWATS effluent fertigated soils (ii) to recommend suitable management practices for environmental protection.

Materials and methods

The study was done at Newlands-Mashu research site, Durban, KwaZulu-Natal, South Africa (30°57'E, 29°58'S). The soil at the experimental site is a clay loam classified as a Sepane (Se), an Aquic Haplustalf (Soil Survey Staff 2014).

A field experiment was conducted in a randomised complete block design with three blocks. There were two treatments (tap water irrigation + inorganic fertiliser vs DEWATS effluent without fertiliser). Banana (*Musa parasidiaca*) and taro (*Colocasia esculentum*) were used as test crops in an intercrop. Initial soil physical properties (texture, water retention, saturated hydraulic conductivity) and chemical properties (soil pH, base saturation, inorganic N and P content, cation exchange capacity and organic matter) were measured according to Non-Affiliated Soil Analysis Work Committee and Soil Science Society of South Africa (1990). The DEWATS effluent was monitored for NO_3^--N, NH_4^+-N and PO_4^{3-}-P according to standard methods (APHA 2005). Leachates were collected from wetting front detectors installed at two soil depths (0.3 and 0.5 m) and were analysed for NO_3^--N, NH_4^+-N and PO_4^{3-}-P according to standard methods (APHA 2005). Banana growth parameters and nutrient uptake were monitored over two growing seasons.

The model was calibrated using tap water + fertiliser treatment information and was validated using both treatments. Crop growth parameters were included in the model according to Jovanovic *et al.* (1999). The soil parameters, effluent qualities, irrigation scheduling and weather information were added to the SWB Sci model according to methods described by Tesfamariam *et al.* (2015).

The model was validated according to criteria described by Tesfamariam *et al.* (2015) where accuracy is considered when $r^2 > 0.8$ and $D > 0.8$.

Results and discussion

Simulation results for the leaf area index and total harvestable dry mass between the two irrigation treatments (DEWATS vs tap water + fertiliser) are given in Table 1. The r^2 and D were all above 0.8 for leaf area index and dry mass (top and harvestable) between the two irrigation treatments hence the model was successfully calibrated.

Table 1. Validation of the SWB model based on banana crop growth data measured at Newlands-Mashu

Variable	Treatment	$^i r^2$	D
Leaf area index	DEWATS	0.87	0.96
Leaf area index	Tap water + fertiliser	0.96	0.97
Top and harvestable dry mass	DEWATS	0.93	0.98
Top and harvestable dry mass	Tap water + fertiliser	0.99	1

The SWB N and P sub-model was calibrated using the data collected on the tap water + fertiliser treatment during the two growing seasons for banana (992 days) as described in Figure 1. The model was successfully calibrated to simulate N uptake in banana (r^2 = 0.97). Validation using the DEWATS treatment showed good prediction results above the recommended 80% (r^2 = 0.95).

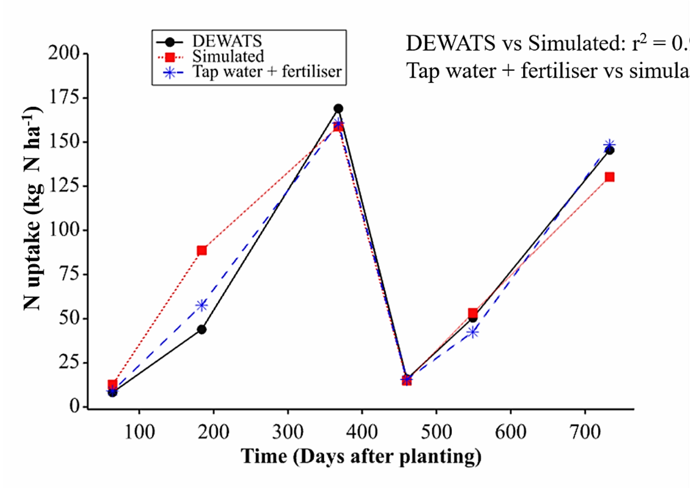

Figure 1. Simulated and measured N uptake during the banana vegetative growth stages between the two irrigation treatments over two seasons

The concentrations of simulated residual N and P in 11 layers of the soil between two irrigation treatments are described in Figure 2. High concentrations of N and P were concentrated in the top 0.3 m depth since the clay loam soil type have high adsorption rate and low hydraulic conductivity (Brady & Weil 2016). Therefore, movement of these nutrients down the soil is expected to be low. The DEWATS effluent showed to increase inorganic N and P content in the soil compared to tap water + fertiliser treatment since it is a source of mineral nutrients (Gutterer *et al.* 2009).

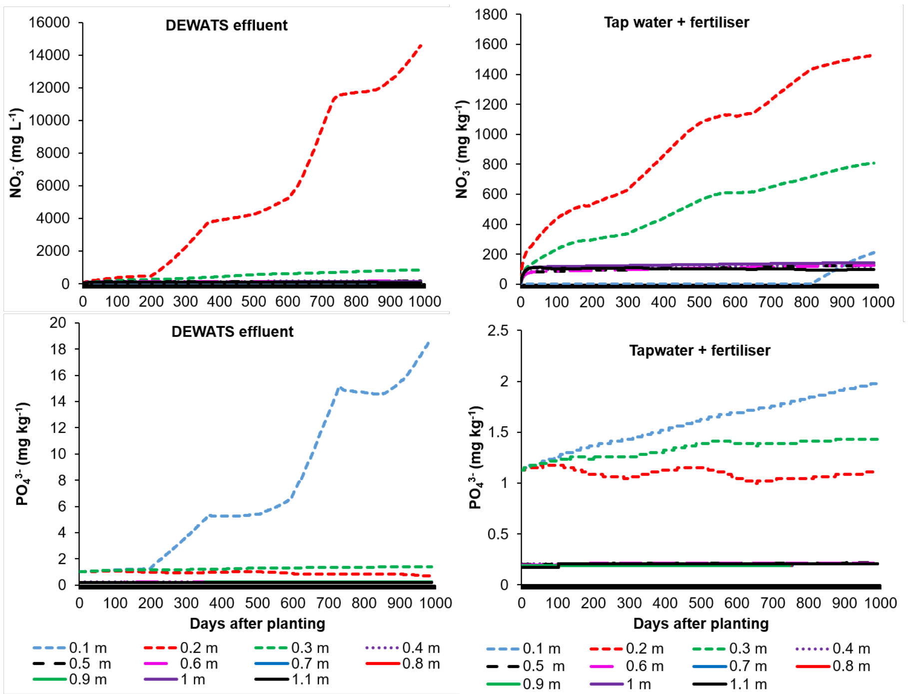

Figure 2. Simulated residual nitrate (N) and labile phosphorus (P) concentrations for irrigation with DEWATS effluent and tap water + fertiliser at different depths (0.1 to 1.1 m) in the Sepane soil at Newlands-Mashu over 992 days.

The SWB Sci simulated cumulative NO_3^- (N) leached from the soil between the two irrigation treatments over a period of 992 days is described in Figure 3. More N was lost in tap water + fertiliser treatment until 826 days after planting. This was different in DEWATS treatment where more losses continued until 992 days after planting. This was due to fast hydrolysis of urea leading to its N loss through leaching.

Conclusions and recommendations

The SWB Sci model was successfully calibrated and could be used reliably to simulate growth and nutrient dynamics in the soil. Irrigation using DEWATS effluent was projected to increase soil inorganic N and P content in the top 0.3 m of a clay loam soil. Nitrate leaching is higher in conventional agricultural practices than DEWATS treatment. Soil N and P monitoring and proper irrigation management practices such as scheduling while considering room for rainfall are recommended for sustainable use of treated wastewater in agriculture.

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References

APHA 2005 *Standard methods for the examination of water and wastewater.* American Public Health Association: Washington D.C

ASHIPALA, N. and ARMITAGE, N. 1988 *Impediments to the adoption of alternative sewerage in South African urban informal settlements.* Water Science and Technology Vol 64, No 9, pp.1781–1789

BRADY, N.C. and WEIL, R.R. 2016 *The Nature and Properties of Soils*. Pearson Prentice Hall: New York.

FAO 1985 *Water quality for agriculture*. Food and Agriculture Organisation: Rome.

GUTTERER, B., SASSE L., PANZERBIETER, T. AND RECKERZÜGEL T. 2009 *Decentralised wastewater treatment systems (DEWATS) and sanitation in developing countries*. BORDA: Bremen.

JARAMILLO, F.M. and RESTREPO, I. 2017 *Wastewater Reuse in Agriculture: A Review about Its Limitations and Benefits*. Sustainability Vol 9, No 10, 1734.

JOVANOVIC, N. and ANNANDALE, J. and MHLAULI, N. 1999 *Field water balance and SWB parameter determination of six winter vegetable species.* Water SA Vol 25, No 2, 191-196.

LEVY, G., FINE, P. and BAR-TAL, A. 2011 *Treated wastewater in agriculture: Use and impacts on the soil environmental and crops.* Wiley: New York.

NON-AFFILIATED SOIL ANALYSIS WORK COMMITEE AND SOIL SCIENCE SOCIETY OF SOUTH AFRICA 2005 *Handbook of standard soil testing methods for advisory purposes.* Soil Science Society of South Africa American Public Health Association: Washington D.C

SOIL SURVEY STAFF 2014 *Keys to soil taxonomy.* Natural Resources Conservation Service: Washington DC.

TESFAMARIAM E. H., ANNANDALE J. G., STEYN J. M., STIRZAKER R. J. and MBAKWE I. 2015 Use of the SWB-Sci model for nitrogen management in sludge-amended land. Agricultural Water Management Vol 152, 262-76.

TILLEY, Elizabeth 1995 *Compendium of sanitation systems and technologies.* Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf.

USEPA 2012 *Guidelines for Water Reuse.* United States Environmental Protection Agency: Washington DC.

WHO 2016 *Sanitation safety planning: manual for safe use and disposal of wastewater, greywater and excreta*. World health organisation: Geneva.

WWAP 2017 *The United Nations World Water Development Report 2017.* UNESCO/WWAP: Paris.

Notes

r^2 is the correlation coefficient

D is the coefficient of agreement

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